# Computer Networks

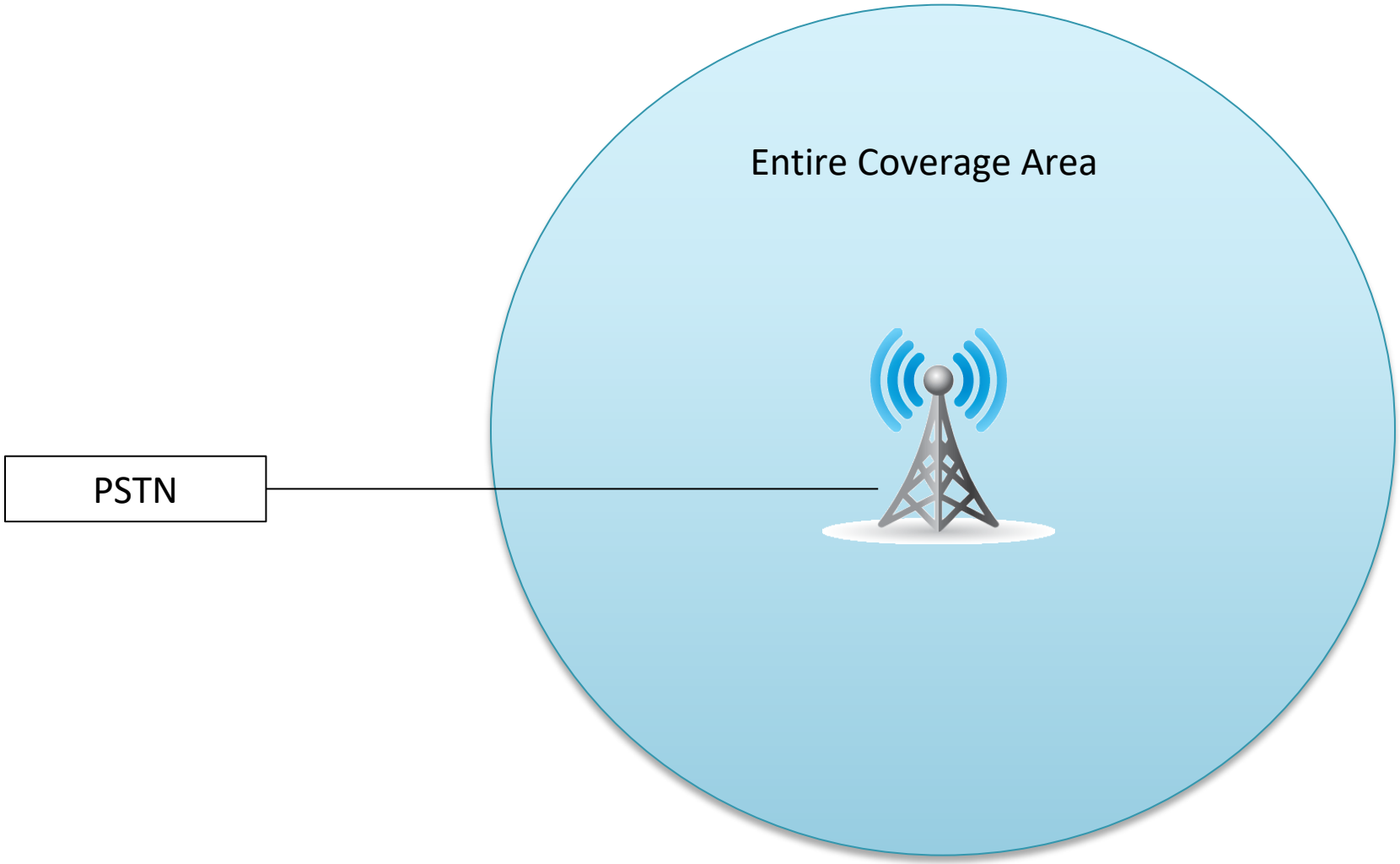
Dr. Ali Sayyed
Department of Computer Science
National University of Computer & Emerging Sciences

# Cellular Networks

# Cellular Network

- Cellular network is an underlying technology for mobile phones, personal communication systems, wireless networking etc.
- First mobile telephone system was developed and inaugurated in the U.S. in 1945.
- This was a simplified version of the system used today.
- A base station provides coverage (communication capabilities) to users on mobile phones within its coverage area.
- Users within the coverage area transmit and receive signals from the base station.
- The base station itself is connected to the PSTN.

# First Mobile Telephone System



# Problem with Original Mobile Telephone System

- Original mobile telephone system could only support **limited users** at a time…over an entire city!
  - Let the available frequency be 1 MHz so it can support 256 voice calls, if one call require 3.4 kHz
- With only one high power base station, users phones also needed to be able to **transmit at high powers.**
  - So that it could reliably transmit signals to the distant base station/tower.
- **Car phones were therefore much more feasible** than handheld phones, e.g., police car phones.
  - Mobile phone has smaller battery and hence less powerful transmitter

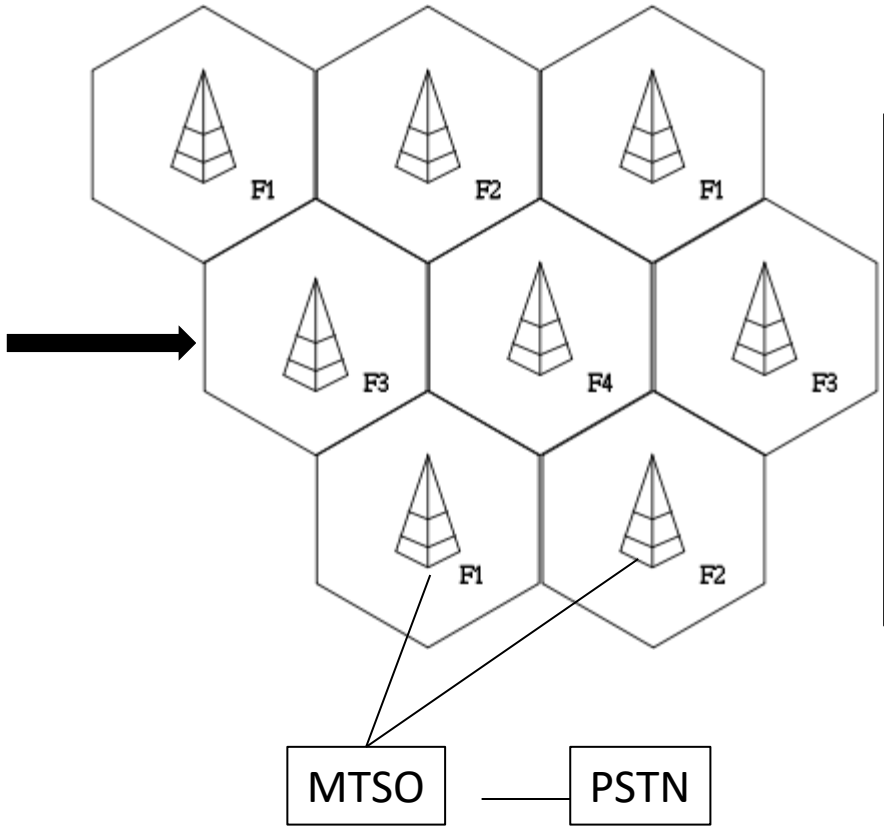
# Improved Design

- Over the next few decades, researchers at AT&T Bell Labs developed the core ideas for today's cellular systems.
- Although these core ideas existed since the 60's, it was only in 80's that electronic equipment became available to realize a cellular system.
- In the mid 80's the first generation of cellular systems was developed and deployed.
- The core idea that led to today's system was the cellular concept.
- **The cellular concept: Multiple**, **lower-power, short-range** base stations that service mobile users within their coverage area and handover/handoff users to neighboring base stations as users move.

# Cellular Concept

- Thus, instead of one base station covering an entire city, the city was broken up into smaller coverage areas called **cell**.
- Each of these cells had its own lower-power base station and antenna.
- Each of these cells had its own range of frequencies.
- User phones in one cell communicate with the base station in that cell.

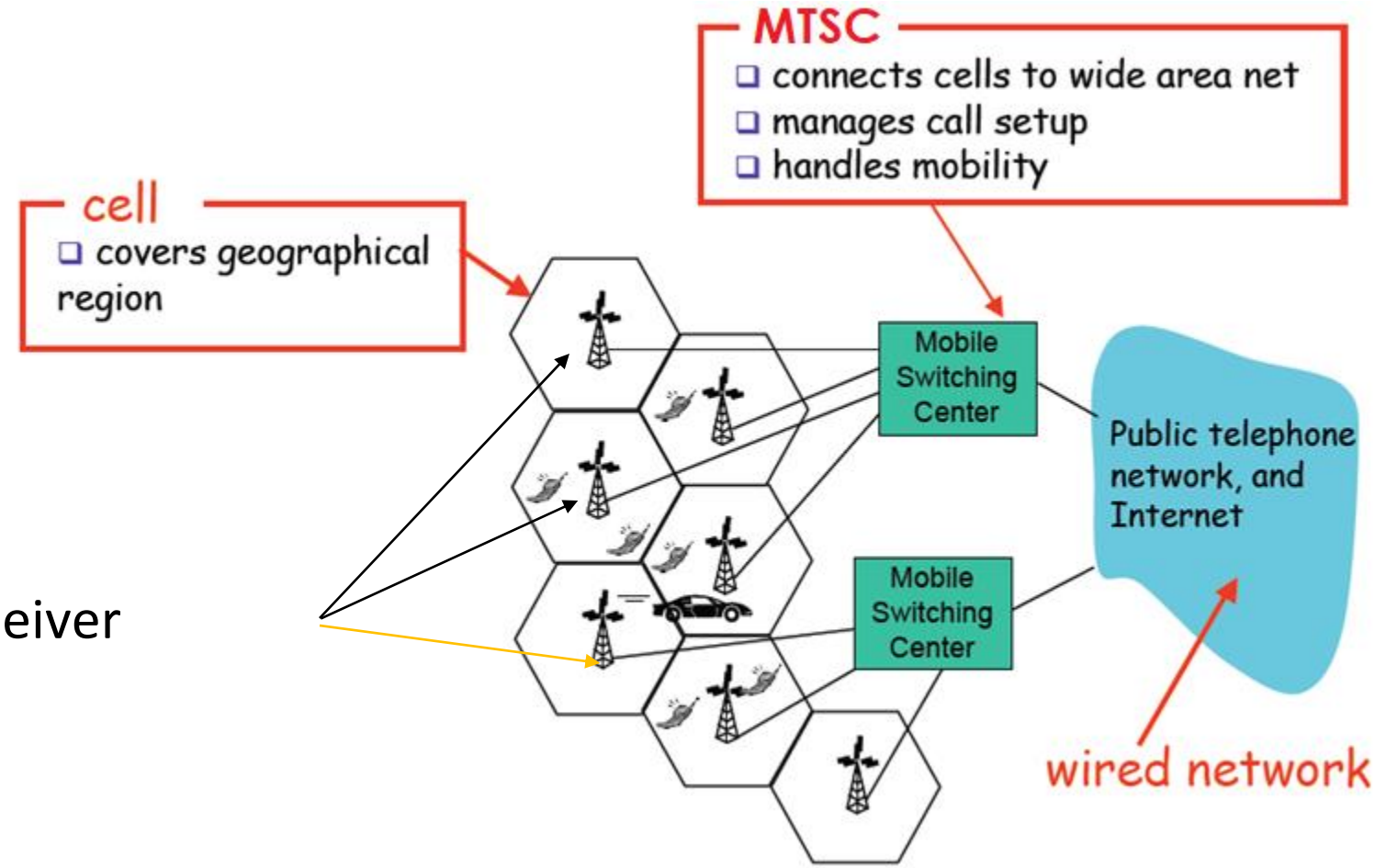
# Improved Design


**Three basic devices**

1. A mobile station
2. A base transceiver Station (BTS)
3. A Mobile Telecommunications Switching Office (MTSO)

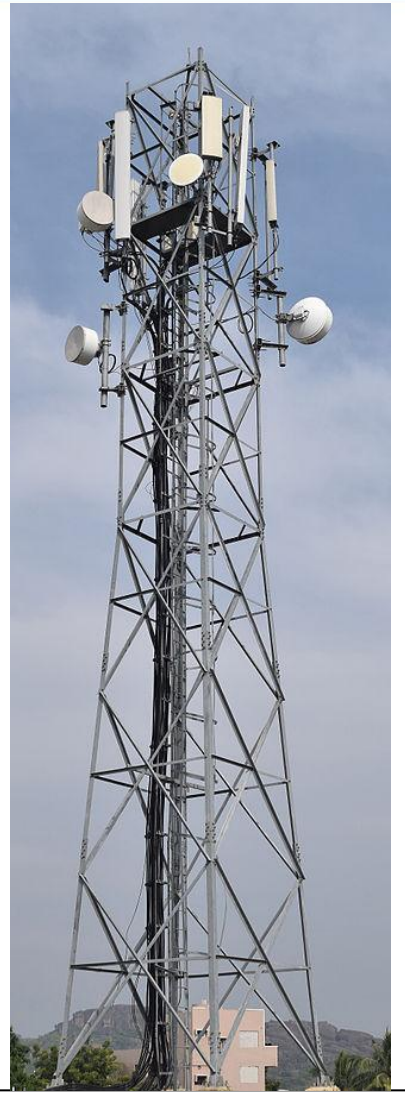
# Cellular Network Architecture




Base Transceiver Station
Or Cell Site

# Base Transceiver Station

- A base transceiver station (BTS) or Cell Site (*is a cellular-enabled device site where antennae and electronic communications equipment are placed over a tower*) facilitates wireless communication between user mobile device and a network.
  - A BTS is usually composed of:
  - Transceiver (TRX)
  - Power amplifier (PA)
  - Multiplexer
  - Antenna
  - Control function etc.



# Mobile Telecommunication Switching Center

- Mobile Telecommunication Switching Center (MTSC) is at core
  - It connect cells BTS to wired network (PSTN)
  - It manage call setup and
  - Manage mobility

- MSC also consists of several databases
  - Home location register (HLR)
  - Visitor location register (VLR)
  - Authentication center database (AuC)
  - Equipment identity register database (EIR)

# Home Location Register (HLR)

- The HLR is an important database as it stores information about the subscribers belonging to the covering area of a MSC.
- The HLR contains information about the subscribers identity, his telephone number, and the associated services.
- It stores the current location of these subscribers and the services to which they have access.

# Visitor Location Register (VLR)

- When a subscriber enters the covering area of a new MSC, It is necessary for the provision of subscribed services to visiting users.
- The VLR associated to this MSC request information about the new subscriber to its corresponding HLR.
- The VLR will then have enough information to assure the subscribed services without needing to confirm with the HLR each time a communication is established.
- The primary role of the VLR is to minimize the number of queries that MSCs have to make to the home location register (HLR), which holds permanent data regarding the mobile user

# The Authentication Center (AuC)

- The AuC register provides the parameters needed for authentication and encryption functions.
- These parameters help verify the user's identity.
- The AuC validates the security information management (SIM) card attempting network connection when a phone has a live network signal.
- 
- Each network SIM card is assigned an individual authentication key ($K_i$). A matching $K_i$ is contained in the AuC. The SIM and the AuC store the $K_i$ in an unreadable format.

# The Equipment Identity Register (EIR)

- The EIR is also used for security purposes.
- The Equipment Identity Register (EIR) is a database that contains a record of the all the mobile stations/phones that are allowed in a network as well as an database of all equipment that is banned, e.g. because it is lost or stolen.
- The identity of the mobile station is given by the International Mobile Equipment Identity (IMEI).
- The EIR uses this to forbid calls from stolen or unauthorized terminals.

# Handover

- In cellular telecommunications, the terms handover or handoff refer to the process of transferring an ongoing call or data session from one cell site (base station) to another without disconnecting the session.
- Network protocols must refresh and renew paths as a mobile station host moves between cells.
- At any time, mobile station (MS) is in one cell and under the control of a BS
  - When a MS leaves a cell, BS notices weak signal
  - BS asks surrounding BSs if they are getting a stronger signal
  - BS transfers ownership to one with strongest signal
  - MTSO assigns new channel to the MS and notifies MS of new boss

# Handover Types

- A handover, in which the source and the target cells are different is called **inter-cell handover**. The purpose of inter-cell handover is to maintain the call as the subscriber is **moving out of the area covered by the source cell and entering the area of the target cell**.

- A special case is possible, in which **the source and the target are one** and the same cell and only the used channel is changed during the handover. Such a handover, in which the cell is not changed, is called **intra-cell handover**. The purpose of intra-cell handover is to change one channel, which may be interfered or fading with a new clearer or less fading channel.

# Handover Types

- **Hard handover** is the one in which the channel in the source cell is released and only then the channel in the target cell is engaged. Thus the connection to the source is broken before the connection to the target is made—for this reason such handovers are also known as **break-before-make**.
- **Soft handover** is one in which the channel in the source cell is retained and used for a while in parallel with the channel in the target cell. In this case the connection to the target is established before the connection to the source is broken, hence this handover is called **make-before-break**. The interval, during which the two connections are used in parallel, may be brief or substantial.
  - When a call is in a state of soft handover, the signal of the best of all used channels can be used for the call at a given moment.

# Good Vs Bad of Hard Handovers

- At any moment in time one call uses **only one channel**. The hard handover event is indeed very short and usually is **not perceptible by the user**. In the old analog systems it could be heard as a click or a very short beep; in digital systems it is unnoticeable.

- The phone's hardware does **not need to be capable of receiving two or more channels in parallel**, which makes it cheaper and simpler.

- A disadvantage is that if a handover fails the **call may be temporarily disrupted or even terminated abnormally**.

# Good Vs Bad of Soft Handovers

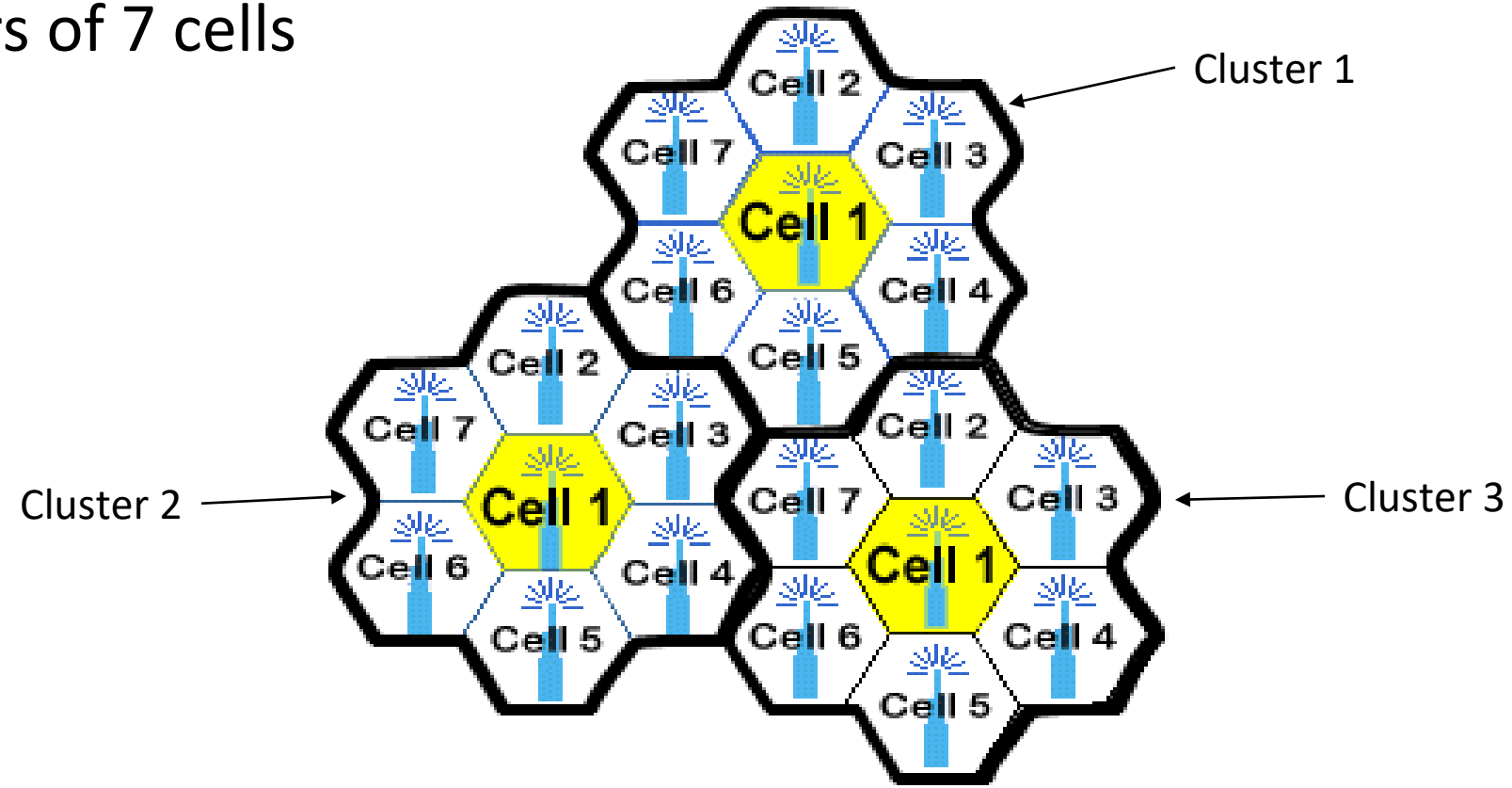
- The connection to the source cell is broken only when a reliable connection to the target cell has been established and therefore the **chances that the call will be terminated abnormally due to failed handovers are lower**.

- More **complex hardware** in the phone, which must be capable of processing several channels in parallel.

- Another price to pay for soft handovers is **use of several channels** in the network to support just a single call. This reduces the number of remaining free channels and thus reduces the capacity of the network

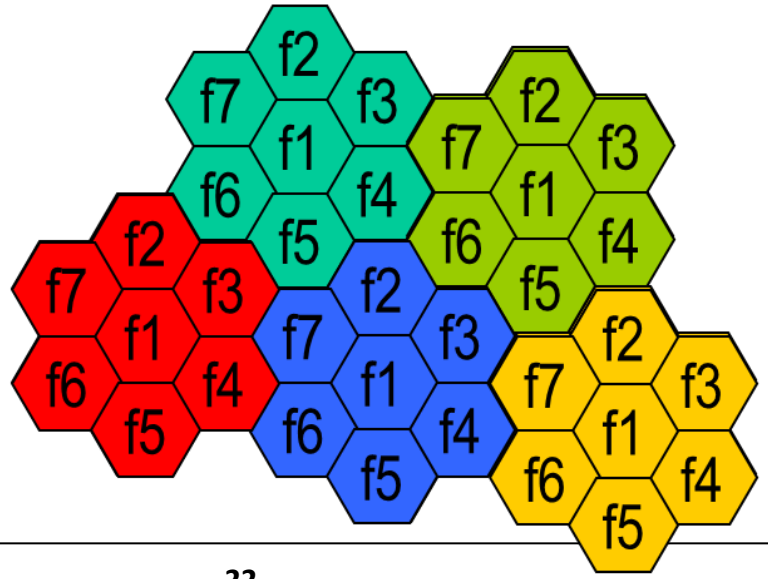
# Cell Clusters

- The available channels (frequencies) are distributed among a group of cells, called Cell Cluster.
- Clusters of 7 cells



# Frequency Reuse

- The concept of frequency reuse is based on assigning to each cell a group of radio channels
- Cells are assigned a group of channels that is completely different from neighboring cells
- The group of frequencies can be reused in other cells, provided that the same frequencies are not reused in adjacent neighboring cells.



# Cluster Size and Channel Cpacity

- Cluster Size (N) is calculated as

$$N = i^2 + ij + j^2,$$

where $i$ and $j$ are non-negative integers such that $i \geq 1$; $i \geq j$.

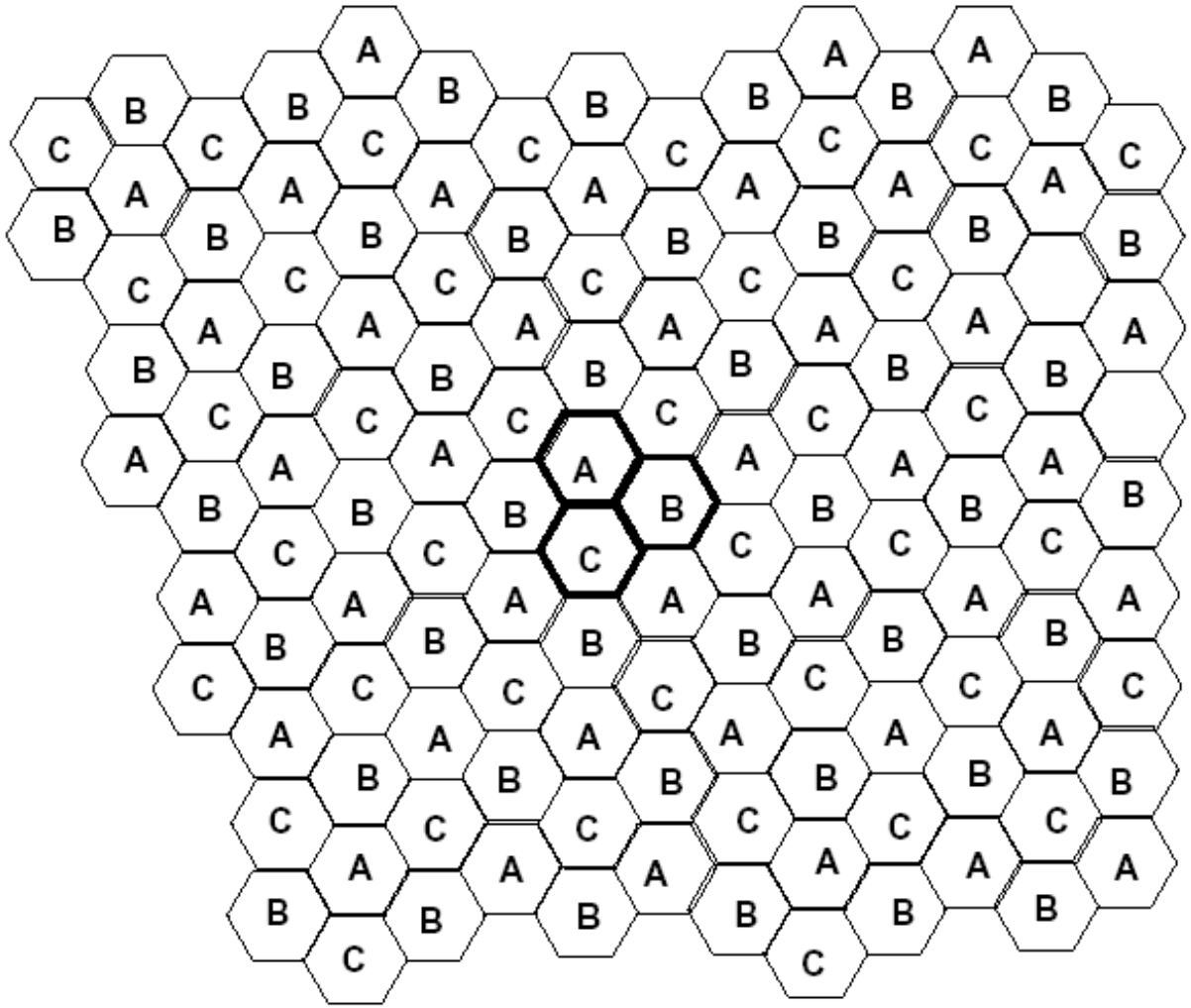
So $N = 1, 3, 4, 7, 9, 12, 13, 16, 19, 21, 27, \ldots$ are allowable cluster sizes.

- And Channel Capacity (C) as

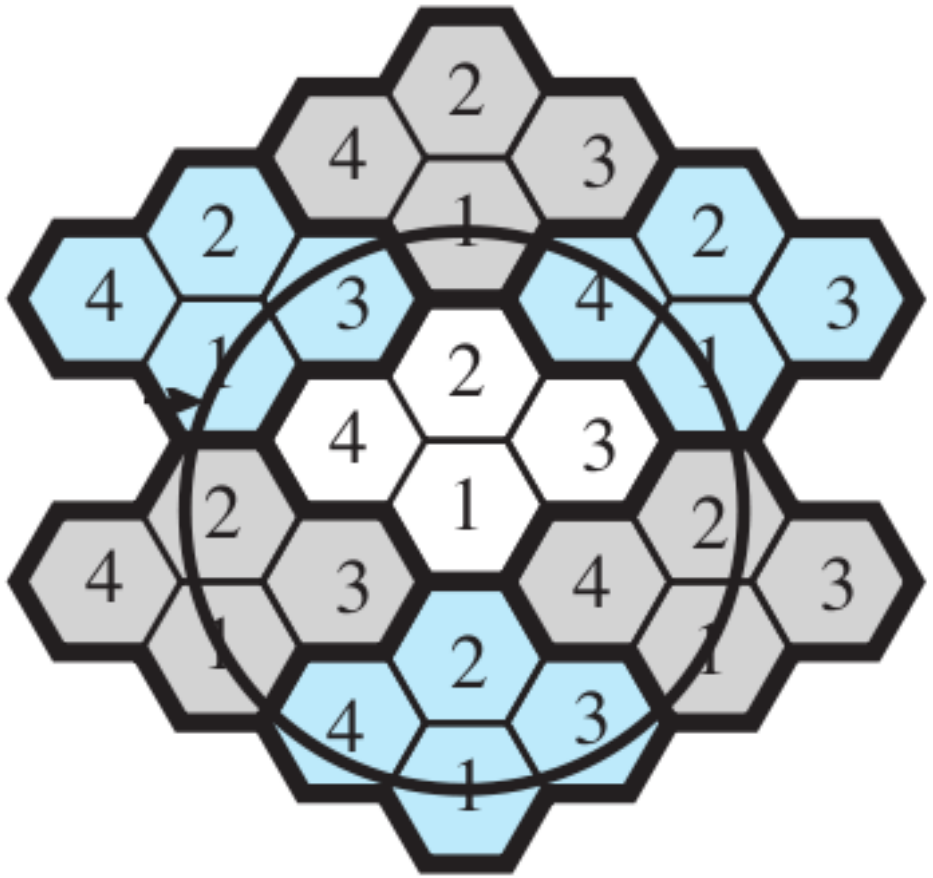
Hence, if there are $K$ cells and a total of $M$ channels with a reuse factor of $N$, the total channel capacity $C$ in the system is

$$C = \lfloor \frac{M}{N} \rfloor K$$

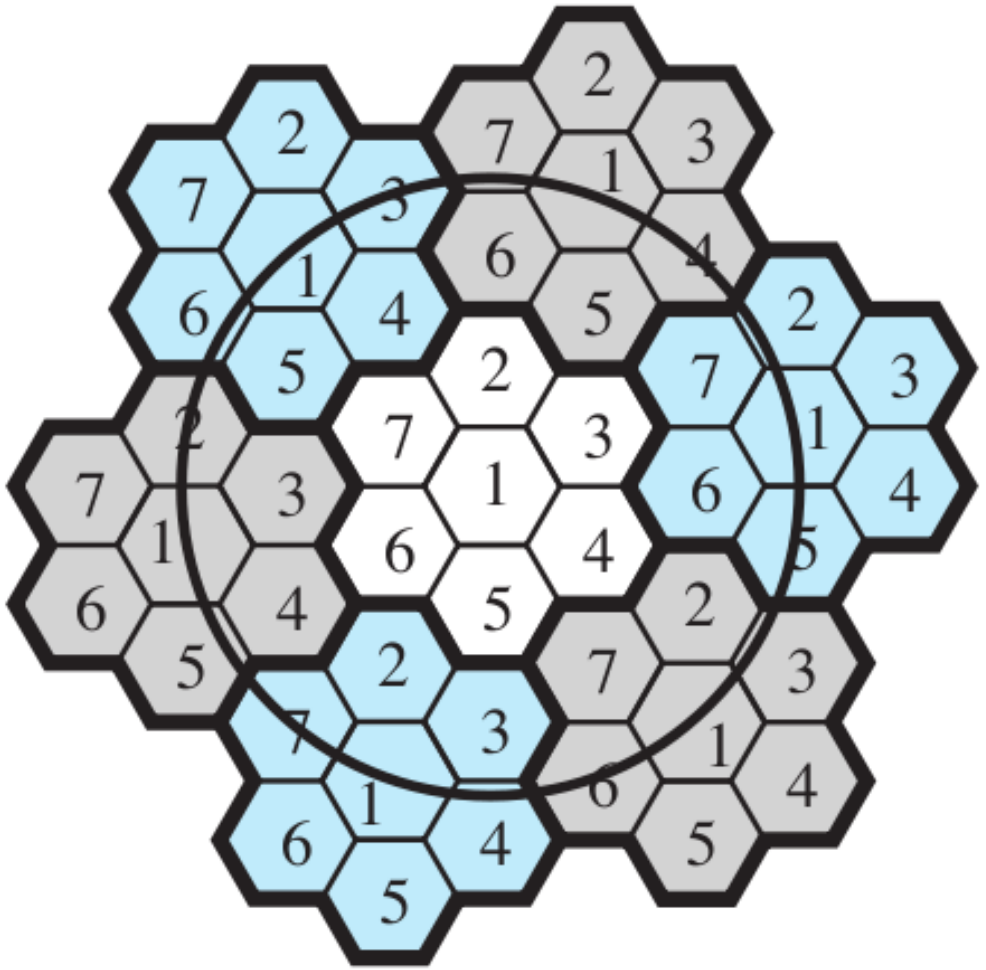
# 3-cell reuse pattern (i=1,j=1)



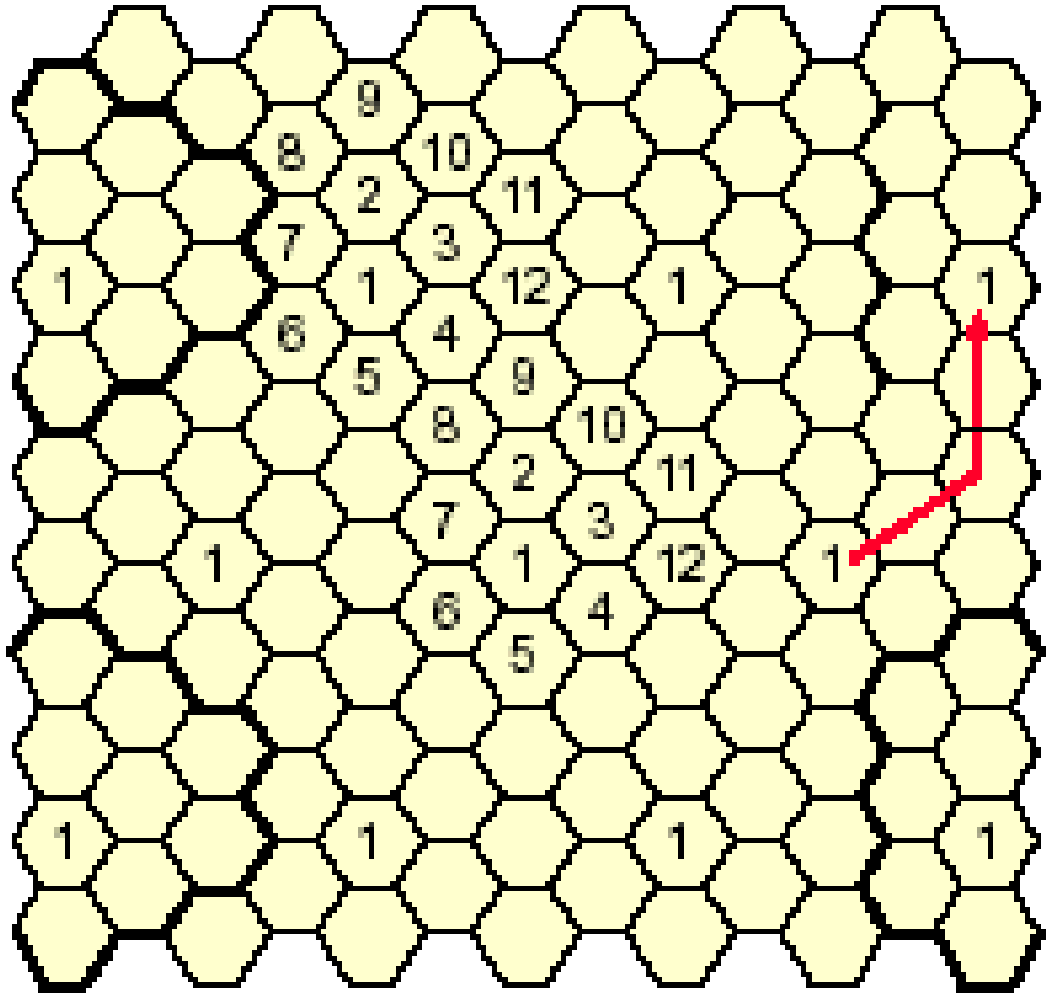
# 4-cell reuse pattern (i=2,j=0)



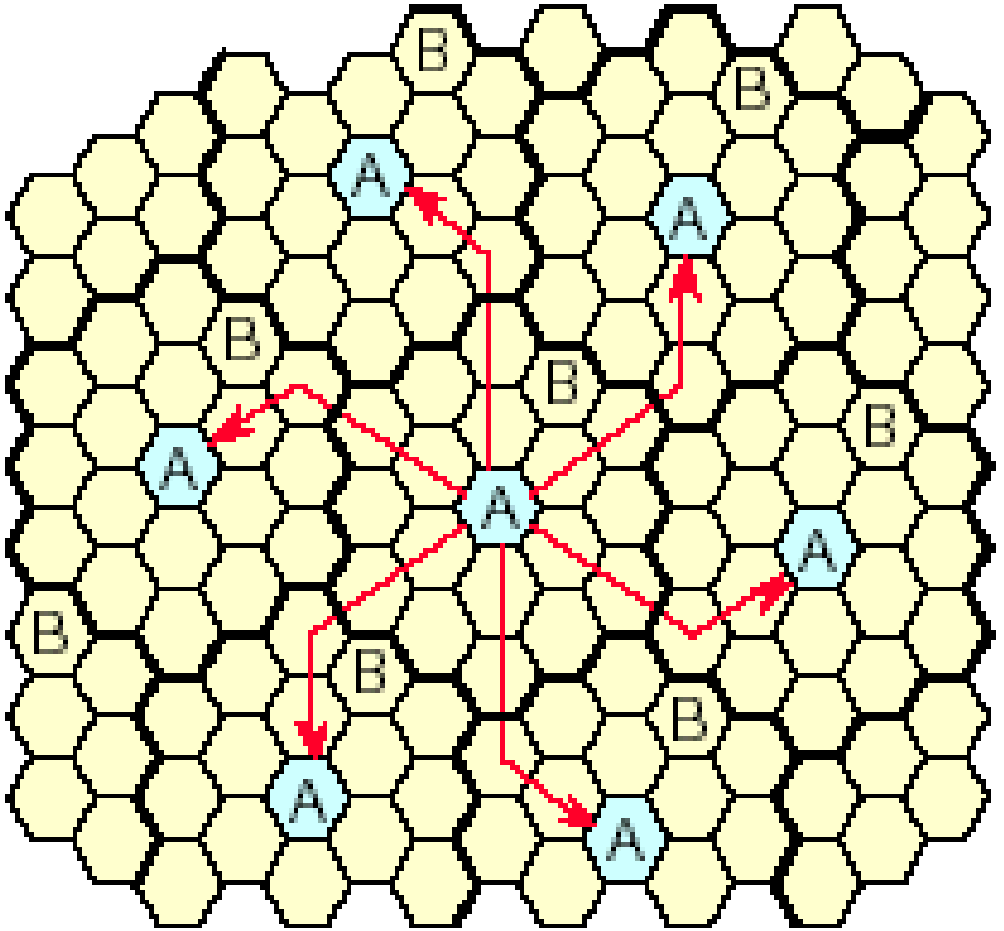
# 7-cell reuse pattern (i=2,j=1)



# 12-cell reuse pattern (i=2,j=2)

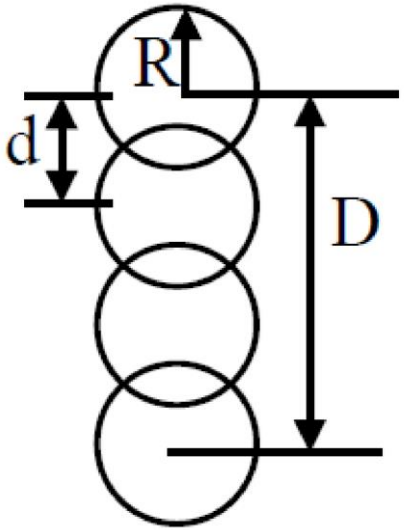


# 19-cell reuse pattern (i=3,j=2)



# Frequency Reuse Distance

- Frequency Reused Distance (D) = $R\sqrt{3N}$
- Frequency Reused Distance (D) = $d\sqrt{N}$

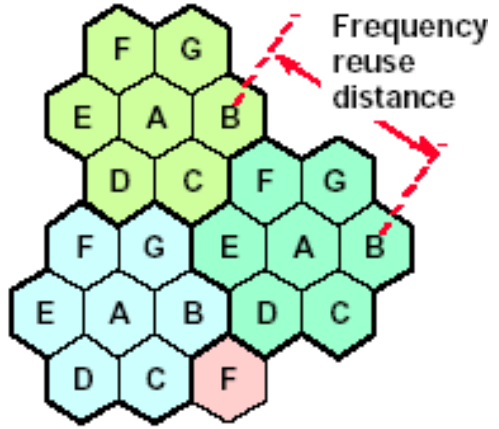



What would be the minimum distance between the centers of two cells with the same band of frequencies if cell radius is 1 km and the reuse factor is 12?

$$D/R = \sqrt{3N}$$

$$D = (3\times12)^{1/2} \times 1 \text{ km}$$

$$= 6 \text{ km}$$




7-cell reuse pattern

# Cell Size

- **Macro cells:** Macro cells are **large cells** that are usually used for remote or sparsely populated areas. These may be 10 km or possibly more in diameter.
- **Micro cells:** Micro cells are those that are **normally found in densely populated** areas which may have a diameter of around 1 km.
  - As cells become smaller, antennas move from the tops of tall buildings or hill to the top of small buildings, where they form microcells.
- **Pico cells:** Picocells are generally used for **covering very small areas** such as particular areas of buildings, or possibly tunnels where coverage from a larger cell in the cellular system is not possible.
  - Obviously for the small cells, the power levels used by the base stations are much lower.

# Approaches to Increase Capacity

- Following approaches are used.
  - Adding new channels
  - Frequency borrowing
  - Cell splitting
  - Cell sectoring

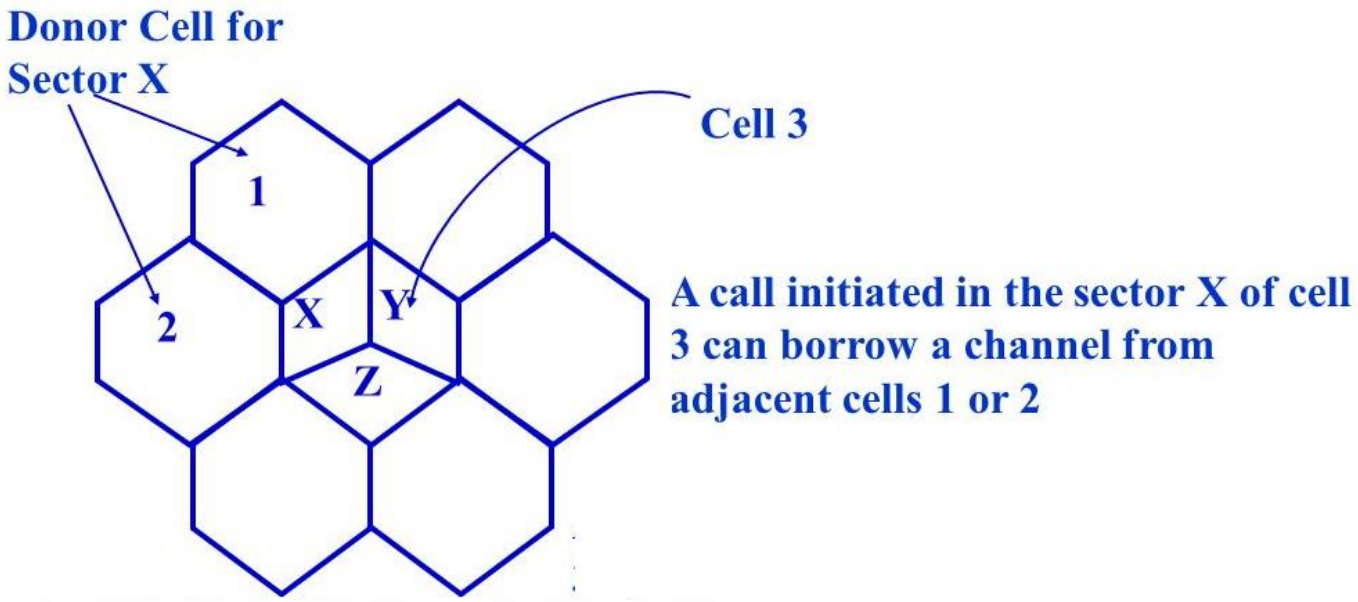
# Increase Capacity - Adding Channels

- Adding new channels Typically, when a system is set up in a region

- Growth and expansion can be managed and increased in an orderly fashion by adding new channels.

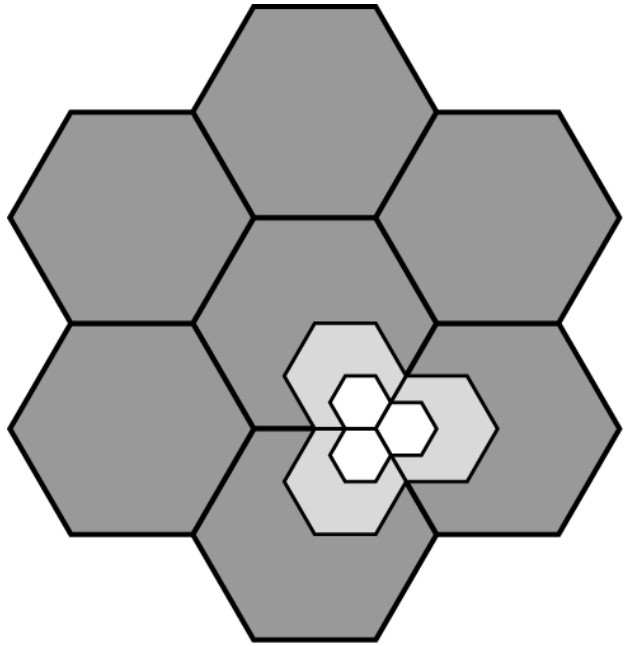
# Increase Capacity - Frequency Borrowing

- Frequencies are taken from adjacent cells by congested cells
- Dynamic assignment of frequencies to different cells
  - Taken from adjacent cells by congested cells
  - Or assign frequencies dynamically



# Increase Capacity - Cell Splitting

- It is the process of splitting a congested cell into smaller cells each with its own base station.
- It increases the capacity of a cellular system since it increases the number of times that channels are reused.
- The increased number of cells would increase the number of clusters over the coverage region, which in turn would increase the number of channels, and the capacity, in the coverage area.
- It allows a system to grow by replacing large cells with smaller cells, while not upsetting the channel allocation scheme

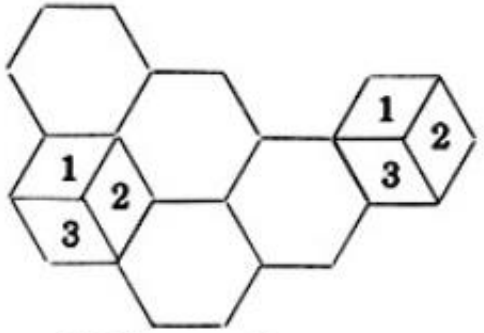


# Decreasing cell size gives

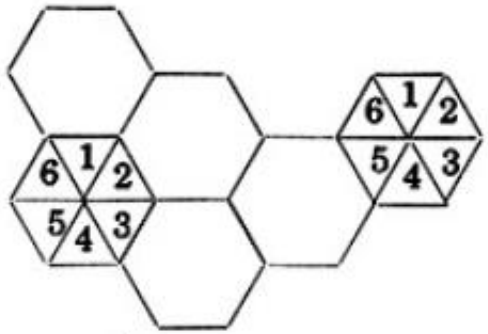
- Increased user capacity due to more frequency reuse
- Increased number of handovers per call
- Increased complexity in locating the subscriber
- Lower power consumption in mobile terminal: so it gives longer talk time

# Increase Capacity - Cell Sectoring

- Cell divided into sectors
- 3 – 6 sectors per cell
- Each with own channel set
  - Subsets of cell's channels



120° sectoring



60° sectoring

- Directional antennas are used at the base station to focus on each sector.
- The co-channel interference in a cellular system may be decreased by replacing a single omni directional antenna at the base station by several directional antennas, each radiating within a specified sector.

# 1G: First-Generation

- A "generation" generally refers to a change in the fundamental nature of the service
- 1G was Totally Analog
- For voice-only communication
- No Security

- **Security Issues with 1G**
  - Analog cellular phones are insecure
  - Anyone with an all band radio receiver can listen to anyone

# 2G

- **From analog to digital:** first-generation systems are almost purely analog (use analog modulation techniques); second generation systems are digital
- **From non-encrypted to encryption** – 2G systems provide encryption
- **Improved channel access** – 2G provide support for channels to be dynamically shared by a number of users
- **Error detection and correction** – second-generation digital traffic allows for detection and correction, giving clear voice reception
- GSM in Europe
  - Digital-AMPS (DAMPS) in US
  - Personal Digital Cellular (PDC) in Japan

# 3G

- Required to provide telephone service as well as data communications at significantly higher speeds, up to 2 Mbps
- Uses CDMA as channel access mechanism
- Major standards
  - Universal Mobile Telecommunications Service (UMTS),
    - Data service: up to 3Mbps
  - CDMA-2000
    - Data service: up to 14 Mbps

# 4G

- From circuit-switched telephony service to all-Internet Protocol (IP) based communication
- When fully implemented, 4G is expected to enable simultaneous connections to multiple high-speed networks which provide seamless handoffs throughout a geographical area, HD mobile TV, video conferencing, online gaming and so on
- Setting peak speed at 100 Mbit/s for high mobility communication (trains, cars etc.) and 1 Gbit/s for low mobility communication (pedestrians and stationary users)
- Use scalable channel bandwidths of 5–20 MHz
- However, different non 4G networks are sometimes also branded as 4G

# 5G

- 5G is the proposed next telecommunications standards.
- 5G aims at higher capacity than current 4G, allowing a higher density of mobile users, and supporting device-to-device, more reliable, and massive machine communications.
- 5G research and development also aims at lower latency than 4G equipment and lower battery consumption, for better implementation of the Internet of things.